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Mechanical Tests of FAA-E2491 Airport In-Pavement Approach and Threshold Lights

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

CONTENTS

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Donald C. Robinson

ABSTRACT

Static and impact load tests were performed on old and new styles of one manufacturer's design for FAA-E-2491 airport in-pavement approach and threshold lights which were mounted in light bases encased in concrete. Static tests were conducted on five lights using either a 6-inch diameter steel plate or a rubber pad through which loads were applied to the center of the light optical cover assembly. Drop tests were conducted on one light using a 5-lb steel ball which was directed to impact at various locations on the optical cover assembly. The old style lights were found to comply with load requirements for the current specification. The maximum load sustained by both style lights when loaded through a rubber pad was about two-thirds of the maximum load sustained when loading directly through the steel plate. A discussion is given of the photometric measurements of the light beam displacement measured during the load tests, the deflections and strains of two new style lights measured under two loading conditions and the test procedures for determining the performance of approach and threshold lights.

Key words: Airport approach and threshold lights, glass prism, impact tests, light bases, optical cover assembly, photometric measurements, static tests.

1. INTRODUCTION

Type FAA-E-2491 in-pavement approach and threshold lights have failed in runways at airports which accommodate modern large aircraft such as the 747 and DC-10. The Federal Aviation Administration has suggested that some of the failures may be related to larger loads imposed by these "jumbo jets" than the loads encountered during the development period for writing the current specification. The majority of the light mechanical failures have resulted in fracture of the glass prisms. However, other failures are characterized by the prism being pushed into the optical cover assembly with no glass fracture. The design of these lights which have failed in service ("old style") was therefore changed by one manufacturer to a "new style" in order to accommodate larger, but heretofore undetermined, service loads.

Subsequently, the Federal Aviation Administration requested that a series of mechanical tests be performed on two old style lights of the type which have had a high failure rate and four of these new style lights, all made by the same manufacturer. The objectives of this program were (1) determine if the old style lights would meet the load bearing requirements for the existing specification, (2) evaluate the capability of the new style lights to meet current specification requirements and (3) to obtain data for possible revision of the specification to increase the load support capabilities of the lights.

Static tests were conducted on the old and new style lights by applying the loads directly through a 6-inch diameter steel plate, or through a rubber pad to simulate loading through a tire. In addition, impact tests were conducted on a new style light by dropping a steel ball at various locations on the light optical cover assembly.

2. TEST SPECIMENS

2.1 Airport Marker Light Base

Type LB-4 airport marker light bases were used in the tests. Three of these bases were each encased in a 3-foot diameter by 3-foot deep concrete cylinder in order to simulate a runway installation.* The bases were cast in the inverted position in order to insure intimate contact between the base and concrete. Reinforcing steel was placed near the top surface of the concrete in order to minimize cracks [1].**

After the concrete hardened, 7/16-inch diameter threaded bolt holes were made in the flange at the top of the bases in order to install steel adapter rings to which the light units were attached. The adapter rings were installed according to procedures given in Reference 2 with one modification, which was approved by the Federal Aviation Administration. The latter involved the use of a gypsum plaster having a bearing strength in excess of the base concrete strength, which was used between the base flange and the adapter ring, and concrete grout for filling the void around the outer edge of the ring.

2.2 Approach and Threshold Lights

Two old style approach and threshold lights, which were removed from a runway, were furnished for testing. The top surface of the optical cover assembly above the prism for both of these lights appeared to be concave and the prism for one of the units had been damaged. The prism had fractures at each end and had rotated within the opening in the optical cover assembly in which it was molded. The damaged unit was repaired prior to being tested

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*U.S. customary units of measurement have been used throughout this report. Readers interested in making use of the coherent system of SI units will find conversion factors in "ASTM Standard Metric Practice Guide" (Designation: E380-72) available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa., 19103.

**Numbers in brackets indicate references given at the end of this report.

by an official from the manufacturer who installed and molded a new prism in the cover assembly.

Four new style lights were furnished for testing. It was observed that the top surface of the optical cover assembly for these lights above the prism were all convex. Adapter rings and all bolts and lock washers necessary for assembly were also supplied. All of the lights tested were produced by one manufacturer.

A schematic of a light unit installed in the LB-4 base encased in a concrete cylinder is shown in Figure 1 and a photograph showing the exposed optical cover assembly and adapter ring for the installed light is given in Figure 2.

3. INSTRUMENTATION

3.1 Airport Marker Light Base

During tests of airport marker light bases prior to development of the adapter rings, failure modes had been generated in the base flange and sidewall [3]. As a consequence of this experience, it was decided to mount a strain gage to the LB-4 base flange and another to the base sidewall to measure the strain in the base during the static tests. These strains proved to be quite small (600×10^{-6} or less) and no permanent deformation occurred in the base during any of the static tests.

3.2 Optical Cover Assembly

The optical cover assembly casting was instrumented to determine the strain at several locations and to measure its deflection during two static load tests of the new style lights. Figure 3 shows the relative position of the strain gages which were attached to the recessed area behind the prism on the under side of the optical cover assembly. The casting surface was ground smooth and cleaned prior to installation of the gages.

In order to measure the deflection of the cover assembly, a small hole was drilled and tapped in the center of the recessed area and a fixture was installed for later attachment to a displacement transducer. The transducer chosen for this purpose was a direct current differential transformer (DCDT), having a sensitivity of 1.50 volts per inch. The DCDT coil assembly was clamped to a bar whose magnetic base was secured to the base of the LB-4 light base. The core was then attached to the fixture on the optical cover assembly just prior to installing the light to the adapter ring. It was necessary to remove the lower portion of the light unit in order to provide for the above instrumentation of the cover assembly.

3.3 Glass Prism

The glass prism in the optical cover assembly was instrumented to determine the strain during static load tests of one old style and two new style lights. Figure 3 shows the location of the strain gages for a static test. In addition, a small displacement range DCDT was mounted to the under side of the optical cover assembly in order to measure deflection of the prism during a static load test on one old style light. The transducer used for this purpose had a sensitivity of 6.02 volts per inch.

4. TEST PROCEDURES

The static load tests were performed in a 400,000 lbf capacity universal testing machine. The LB-4 light base encased in concrete was placed on a 36-inch diameter by 0.75-inch piece of plywood to protect the machine platen. All of the lights were installed in accordance with procedures given in Reference 2. Static loads were applied using either a 6-inch diameter by $1\frac{1}{4}$-inch thick steel plate or using a rubber pad having a Shore A hardness of 55 to 65 through which the loads were transferred to the cover assembly. Figure 4 shows the set-up when using the 6-inch diameter plate. When the rubber pad was employed, it was compressed by a large steel plate which overlapped the top of the optical cover assembly, as shown in Figure 5.

The signals from the strain gages and displacement transducer were fed to signal conditioning equipment and the data were digitized and recorded on a paper tape, using a multichannel data acquisition system.

4.1 Static Load Tests of Old Style Light

The old style light without obvious damage, Serial No. 267, was tested to determine if it met the static load bearing requirements of Specification FAA-E-2491a [4]. Static loads were applied to the center of the top of the optical cover assembly through a 6-inch diameter by $1\frac{1}{4}$-inch thick steel plate. The load was applied at a rate of 20,000 lbf per minute to a maximum load of 80,000 lbf, this load was maintained for 2 minutes, and then removed.

Since no failure was observed, a subsequent load test was conducted at the request of the Federal Aviation Administration in which the load was applied at a rate of 20,000 lbf per minute until failure occurred. Photometric measurements were made before and after this test to determine the light beam displacement.

4.2 Static Load Tests of New Style Light

Static load tests were conducted on a new style light, Serial No. 676, according to the test program given in Appendix A which was furnished by the Federal Aviation Administration. Before the load test began, an initial photometric scan was made for a reference of the light output displacement. For this test, a rubber pad of Shore A hardness 55 to 65 was placed over the light and a flat steel plate which overlapped the top portion of the optical cover assembly was placed over the pad. The load was applied at a rate of 20,000 lbf per minute to a load of 76,000 lbf, this load was maintained for 5 minutes, and then removed. Photometric measurements were made after the load was removed to determine displacement of the light beam.

After this test, in which no failure occurred, the rubber pad and steel plate were removed and a 6-inch diameter by 1¼-inch thick steel plate was centered over the light. Loads were applied to the light using this test fixture at a rate of 20,000 lbf per minute until failure occurred.

4.3 Static Load Tests of Instrumented New Style Light

A load test was conducted for a new style light, Serial No. 678, which had been instrumented to measure strain at several locations and deflection at one location of the optical cover assembly. The load was applied to the top center of the light through a 6-inch diameter by 1¼-inch thick steel plate, according to the test program in Appendix A. The load was applied at a rate of 20,000 lbf per minute until failure occurred. The strain and deflection data were recorded at load intervals of 10,000 lbf.

A distributed load test was conducted for another new style light, Serial No. 679, which was also instrumented to measure strain and deflection at the request of the Federal Aviation Administration. The test was conducted in the same manner as the load test for the Serial No. 678 new style light with the same measurements, except that the load was applied through a rubber pad to simulate loading through a tire.

4.4 Static Load Test of Instrumented Old Style Light

A distributed load test was conducted for an old style light, Serial No. 664. For this test, the glass prism was instrumented to record both the strain and displacement at the center of the prism, since some runway light failures had involved large prism motion. The load was applied at a rate of 20,000 lbf per minute in the same manner as the distributed load (rubber pad) test for the Serial No. 679 new style light.

4.5 Impact Tests of New Style Light

Impact tests were conducted on a new style light, Serial No. 677, according to the test program given in Appendix A. A complete light unit was installed on the test light base. A 5-lb steel ball with a hardness of Rockwell C66 was dropped through a 3.5-inch diameter metal tube whose upper end was clamped to the moveable crosshead of a universal testing machine.* The tube was first aligned directly over the center of the optical cover assembly and the ball was dropped from a height of 6-feet and constrained after it rebounded from the surface of the cover assembly. Since the light withstood the initial impact test, the position of the tube was varied during subsequent drop tests so that the ball impacted at five different locations on the top of the cover assembly. Each of these locations was approximately ¼-inch from the opening in the cover assembly casting into which the glass prism was molded, i.e. the ball impacted the metal directly above the prism. Figure 6 shows the impact test arrangement which was set up in the same machine used for the static load tests.

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*The Federal Aviation Administration approved the use of a harder ball than indicated in the test program given in Appendix A.

5. TEST RESULTS

5.1 Static Load Tests

The principal results of the static load tests are summarized in Table 1. All of the tests on the new style lights were terminated when the glass prism in the optical cover assembly fractured. These fractures all occurred in the center of the prism, as shown in Figures 7a and 7b. The load versus deflection of the optical cover assembly measured when the lights were loaded through the 6-inch diameter steel plate and through the rubber pad is plotted in Figure 8. The strains measured on the cover assembly during these tests are shown in Figures 9 and 10 and the strains measured on the glass prism are plotted in Figure 11. The measured deflection and strain levels at a given load were generally higher for the distributed load (rubber pad) tests than for the concentrated load (steel plate) tests on the new style lights.

During the test on the old style light, Serial No. 267, when the load was applied to the optical cover assembly by a steel plate, the glass prism was displaced from its initial position in the cover assembly and the test was terminated when the cover assembly casting fractured at a load of 316,500 lbf. After this test, the paint was removed from the cover assembly and dye penetrant was sprayed onto the fractured surface. Photographs of the cracks were then taken when the cover assembly was exposed to an ultra-violet light source. Figure 12 shows the two principal fractures which eminated from the topmost surface of the cover assembly and propagated to the edge of the casting.

When static loads were applied to the repaired old style light, Serial No. 664, through the rubber pad, the test was terminated when the glass prism fractured. The recorded displacement data indicated that the prism had moved outward about .040-inch prior to its fracture. This small amount of motion could not have been determined by visual examination of the prism after the test.

The photometric measurements of the displacement of the light beam were taken during the static load tests of one new style and one old style light. These measurements indicated an angular shift of approximately 0.090 degree during the maximum loads to which the lights were subjected and approximately a 0.030 degree permanent shift from the initial setting following removal of the load. It is unknown how much of the displacement is caused by "seating" of the fixture or the compaction of the test bed itself under load rather than any actual change in the fixture proper. In any case, the small shifts are considered insignificant for the approach light application where relatively wide beams exist.

5.2 Impact Tests

Following each of the impact tests, the light was visually examined. There was no evidence of breakage, fracture or deformation that could cause leaks or shift the light output pattern. These tests were inconclusive in that only one light of one style was tested and no damage occurred.

6. DISCUSSION AND CONCLUSIONS

The two old style lights which were tested complied with the load bearing requirements for the current specification, which has a maximum static load requirement of 80,000 lbf [4]. Three new style lights tested also complied with the specified static load requirements. The old style lights withstood larger compressive loads before failure than the new style lights, whether the loads were applied through a steel plate or through a rubber pad. This result suggests the possibility that factors which were not measured could have influenced the maximum loads which were able to be sustained. Such factors might be tolerances within the optical cover assembly prism opening, tolerances of the glass prism, and/or permanent deformation or residual stresses within the cover assembly. It is not clear from the tests conducted on the old style lights, both of which were removed from runways and one of whose prisms had been obviously damaged, how the load bearing requirements of the current specification should be revised.* It is necessary that some procedures be developed in order to determine the magnitudes of various types of service loads to which the approach and threshold lights are subjected in runways before meaningful bearing loads can be specified. In this regard, it should be noted that the load bearing tests in the current specification are inadequate for duplicating some of the service failures which have been reported; namely, failures where the glass prism is pushed into the optical cover assembly with no fracture occurring.

Both the old and new style lights when loaded through a rubber pad failed at about two-thirds of the bearing load when compressed through a steel plate. Analysis of the deflection and strain data measured for the new style lights indicate that the test when the loads were applied through a rubber pad was more severe than when the loads were applied directly through a steel plate. This observation is based on a small number of tests for lights designed by one manufacturer.

The small shifts in the photometric measurements of the displacement of the light beam are considered insignificant for the approach light application where relatively wide beams exist.

7. RECOMMENDATIONS

It is apparent from the results of the static and impact tests on the airport marker lights that the tests conducted do not provide sufficient information on which to consider revisions of the bearing requirements in the FAA approach light specification [4]. Additional tasks required in order to obtain data for basing such judgments include 1) detailed analyses of approach light service failures and 2) quantification of the service loads experienced by the lights. It is therefore recommended that further research be undertaken in order to develop techniques in the laboratory for field recording and measuring of the critical dynamic service loads

*The tests conducted indicate that old style lights which can withstand twice the specified bearing load have still experienced service failures.

experienced by approach and threshold lights. In order to demonstrate the creditability of such procedures, field measurements should be undertaken to record and measure the service loads at one or two locations on a runway where airport maintenance records reveal the most frequent incidence of light failures due to mechanical loading have occurred. In addition, consideration should be given to supplementing the load bearing tests in the current specification with test procedures in which loads are applied directly to the optical prism in order to simulate service failures in which the prism is pushed into the optical cover assembly.

8. ACKNOWLEDGMENT

The photometric measurements were taken during the mechanical tests by Messrs. W. F. Mullis and M. R. Freund and subsequently analyzed by Mr. Mullis. Instrumentation was provided by Messrs. J. L. Michalak and R. E. Snyder. Photographic assistance was provided by N. Halsey.

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2. In-Pavement Approach Light and Threshold Light Type 19975, Instruction Book 7223 made in accordance with FAA Specification: FAA-E-2491, Sepco Division, Connecticut International Corp.

3. Sushinsky, G. F., Static Tests of L-837 Airport Marker Light Bases, NBS Technical Report 10453 to Federal Aviation Administration, July 1971.

4. Department of Transportation, Federal Aviation Administration Specification FAA-E-2491a, February 19, 1974.

APPENDIX A

Test Program for the FAA-E-2491 Lights

A. Old style lights from Newark Airport.

1. The light with the pushed in prism will be used for study or practice only.

2. The light without obvious damage shall be tested with the concentrated load. The light with attached base unit shall be mounted on one of the encased bases and outer rings. All screws shall be tightened to the torque indicated in SEPCO's Instruction Book 7223. The load shall be applied to the center of the top of the light through the 6-inch diameter, 1¼-inch thick steel plate without the rubber pad or other load block. The total load of 80,000 pounds shall be applied at the rate of 20,000 pounds per minute and the full load maintained for 2 minutes. The light shall have no evidence of cracking or breaking of top assembly or of any component which could cause leaks or permanent distortion to cause shifting of light output.

B. New style lights purchased from SEPCO.

1. Preparations for tests.

   a. Encase three type LB-4 bases in concrete suitable for mounting the FAA-E-2491 lights including outer rings. The concrete shall have a minimum thickness of 6-inches around sides and bottoms of bases except for the hubs. A conduit for bringing in power cables extending through the concrete shall be attached to one of the hubs of each base. Plywood covers, 22½-inches diameter by 1 3/8-inches thick, shall be fastened to the bases with bolts and the concrete around the covers shall extend out to the width of the concrete encasing the bases but need not be a full 6-inches thick around the covers. The encasement may be cast upside down but make certain the surfaces for the outer rings are flat or slightly concave when in the upright positions. High early strength concrete should be used to save time in completing these tests, but this concrete should be cured for at least seven days before load tests are started.

   b. After removing the plywood covers, the threaded bolt holes in the tops of the bases should be drilled out to 7/16-inch diameter before installing the outer rings of the lights.

   c. Install the outer rings according to paragraphs 2.2 and 2.3 of SEPCO Instruction Book 7223 using suitable adhesive and type P606 filler around the rings.

2. Static load tests.

a. Initial load test. Install an optical assembly with a complete sealed unit on one of the test bases and outer rings. Without opening the sealed unit, connect the light to a suitable power source. Before load tests begin, make the initial photometric scans to obtain the data for reference on light output displacement. Then with the power disconnected, make the distributed load tests. For this test, the 1-inch thick rubber pad of Shore A hardness of 55 to 65 is placed over the light, a flat steel plate 18 to 22 inches diameter and 3/4-inch thickness is centered over the light (no contouring except for the rubber pad is required.) The load may be applied directly to this steel plate or through a 6-inch diameter 1¼-inch thick steel plate. The distributed load for this test will total 76,000 pounds which will be applied at the rate of 20,000 pounds per minute, and the total load is held for 5 minutes. After removing the load, inspect for breakage or damage. If damage is not detected, make a concentrated load test. This test is made by applying the load directly to the top center plate without the rubber pad. The load is applied at the rate of 20,000 pounds per minute to a total of 80,000 pounds which is held for 2 minutes. Remove the load, inspect for breakage or damage, and make the photometric scans to check for permanent displacement of the light output. If the light withstands this load satisfactorily, repeat the concentrated load test to a total of 150,000 pounds and hold for 2 minutes, or load to failure. Remove the load, inspect for damage, and make the photometric scans for light output displacement.

b. Strain gage load test. If the light withstood the previous testing use the same light, or if it failed, use another light, remove the sealed unit and install strain gages at points of interest for continued load testing. After the strain gages are installed, mount the light top assembly on a test base and outer ring. Apply the concentrated load test as above to light failure or to 250,000 pounds whichever occurs first. Remove load and inspect for damage.

3. Impact tests.

a. Initial impact test. A complete light unit shall be installed on a test light base. A 5 pound steel ball case hardened to Rockwell C50 to C53 shall be dropped from a height of 6-feet on the center of the light unit. Examine the light for breakage, cracking or deformation that could cause leaks or shift the light output pattern.

b. If the light withstands the initial impact test, continue to make impact tests on other areas of the top assembly
to make impact tests on other areas of the top assembly
to determine the capability of the light to withstand this impact.

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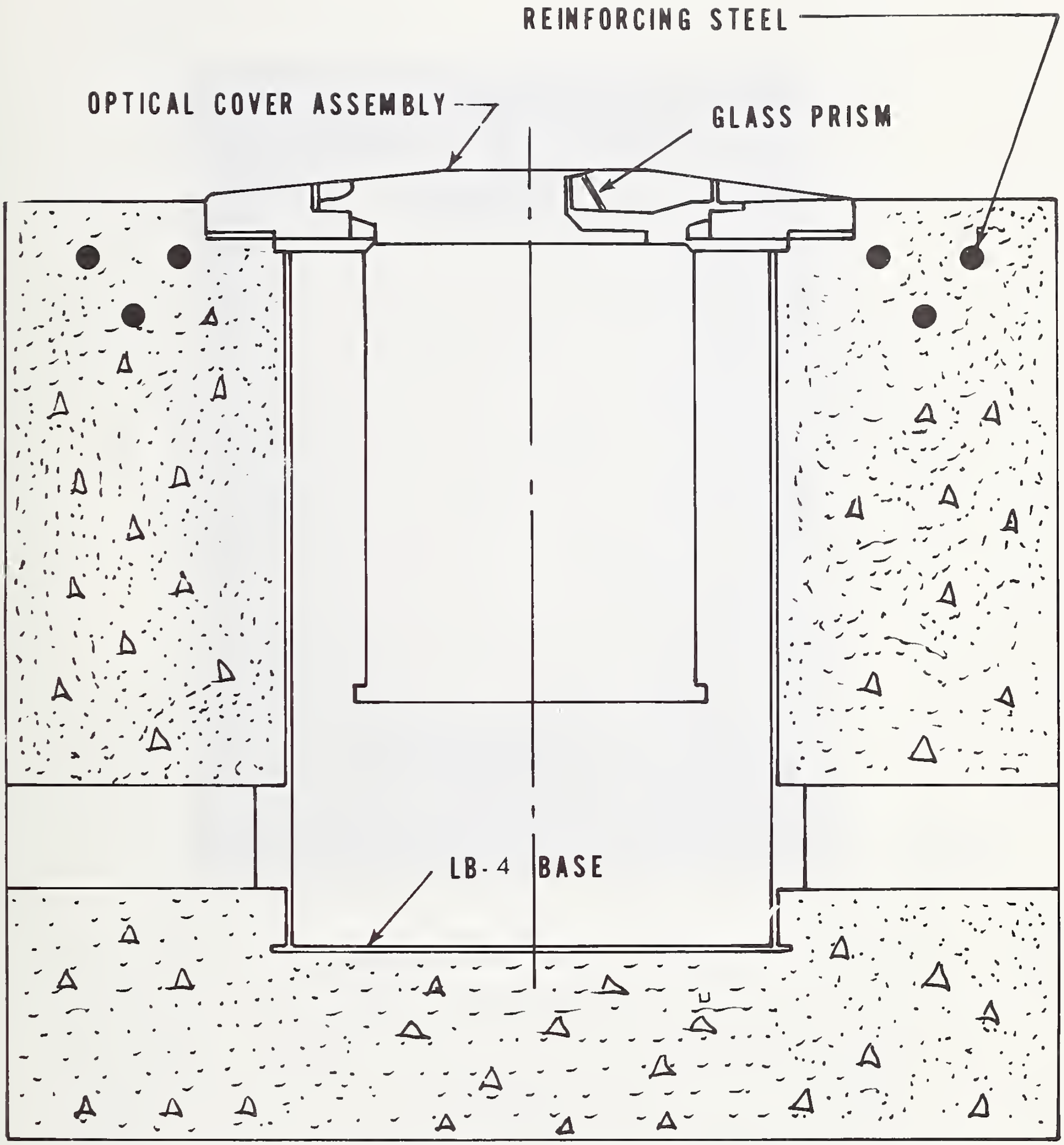

Figure 1 – SCHEMATIC OF AIRPORT MARKER LIGHT ASSEMBLY MOUNTED IN CONCRETE

Figure 2 — Type FAA-E-2491 Airport Marker Light Installed in LB-4 Base Encased in Concrete Cylinder

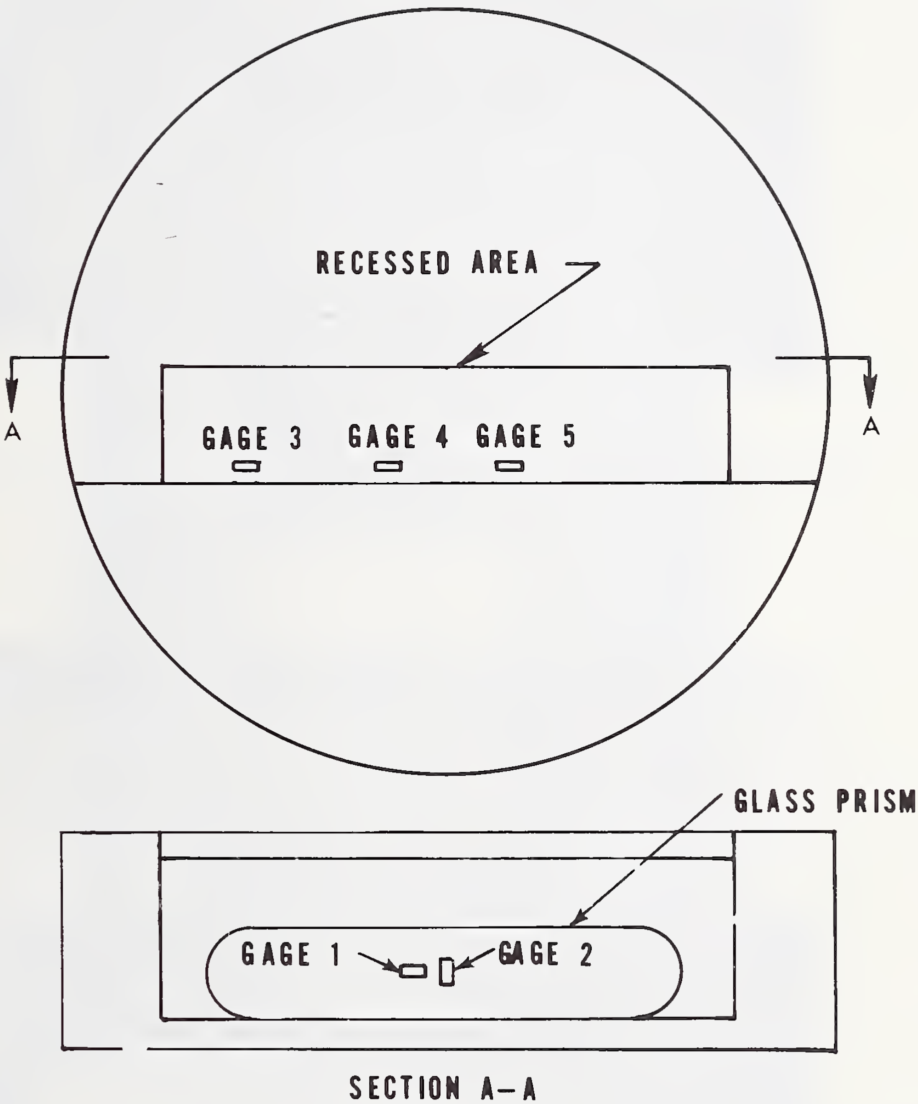

Figure 3 — SCHEMATIC OF OPTICAL COVER ASSEMBLY FOR FAA —E—2491 LIGHT SHOWING STRAIN GAGE LOCATIONS IN RECESSED AREA BEHIND PRISM AND ON PRISM SURFACE

Figure 4 – Static Test Setup Using 6-Inch Diameter Steel Plate for Loading Top of Light Assembly

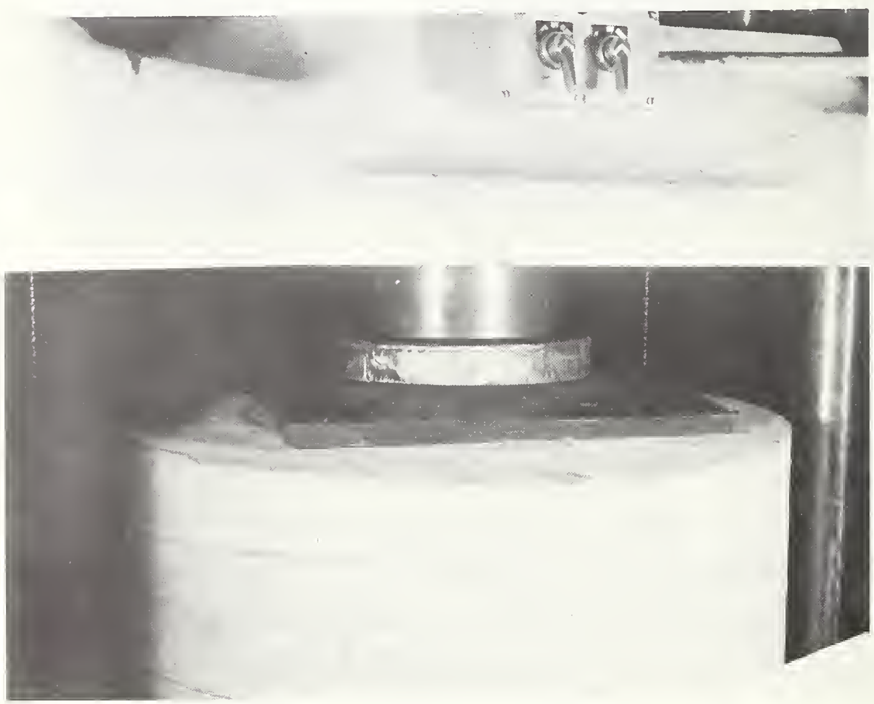

Figure 5 – Static Test Setup Using Rubber Pad for Loading Top of Light Assembly

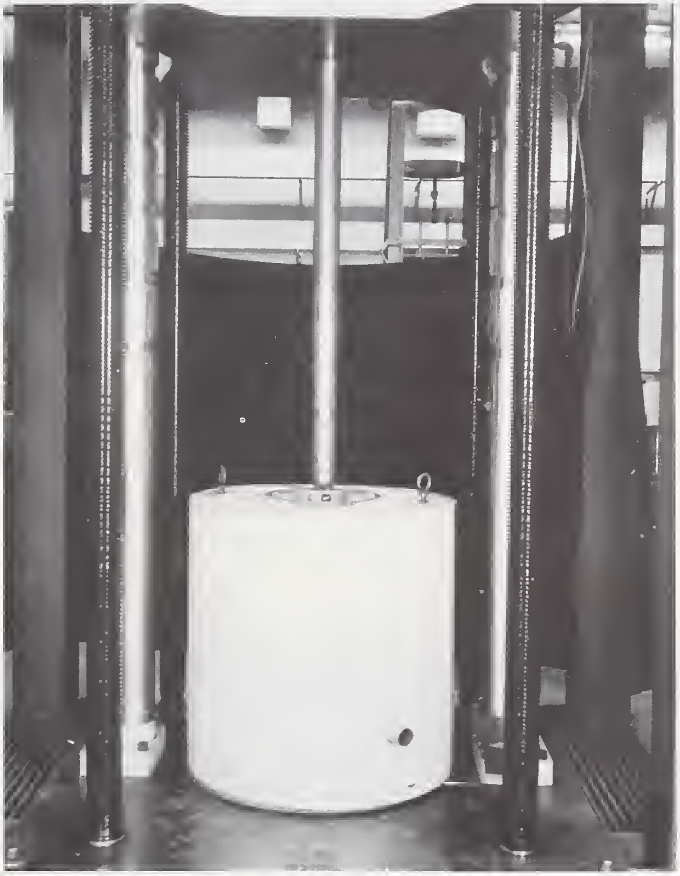

Figure 6 – Impact Test Setup in 400,000 lbf-Capacity Universal Testing Machine

Figure 7a — Prism Fracture Developed During Static Test of New Style FAA-E-2491 Light

Figure 7b — Closeup of Prism Fracture in New Style FAA-E-2491 Light

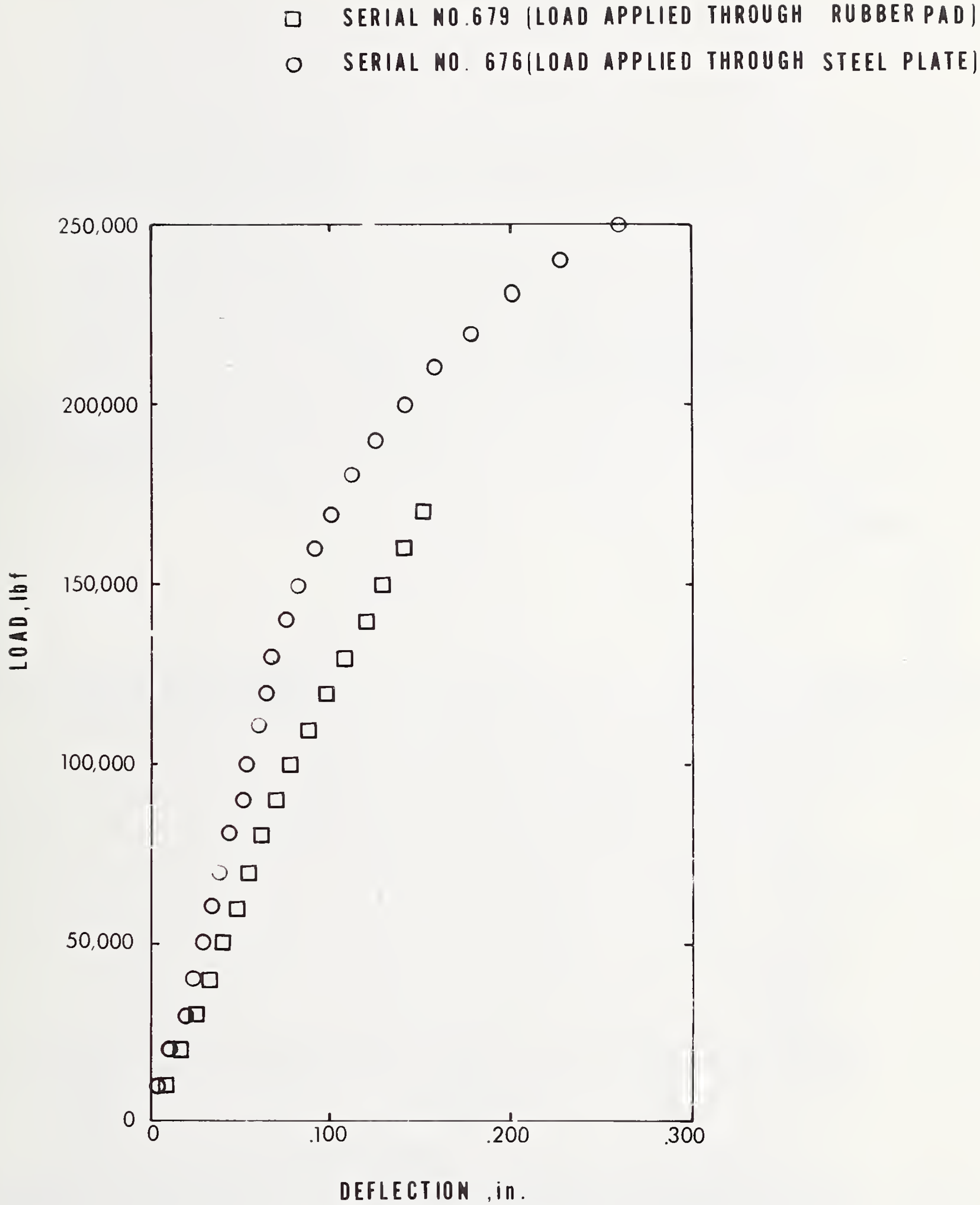

Figure 8 – LOAD VERSUS DEFLECTION OF OPTICAL COVER ASSEMBLY FOR NEW STYLE FAA-E-2491 APPROACH AND THRESHOLD LIGHT

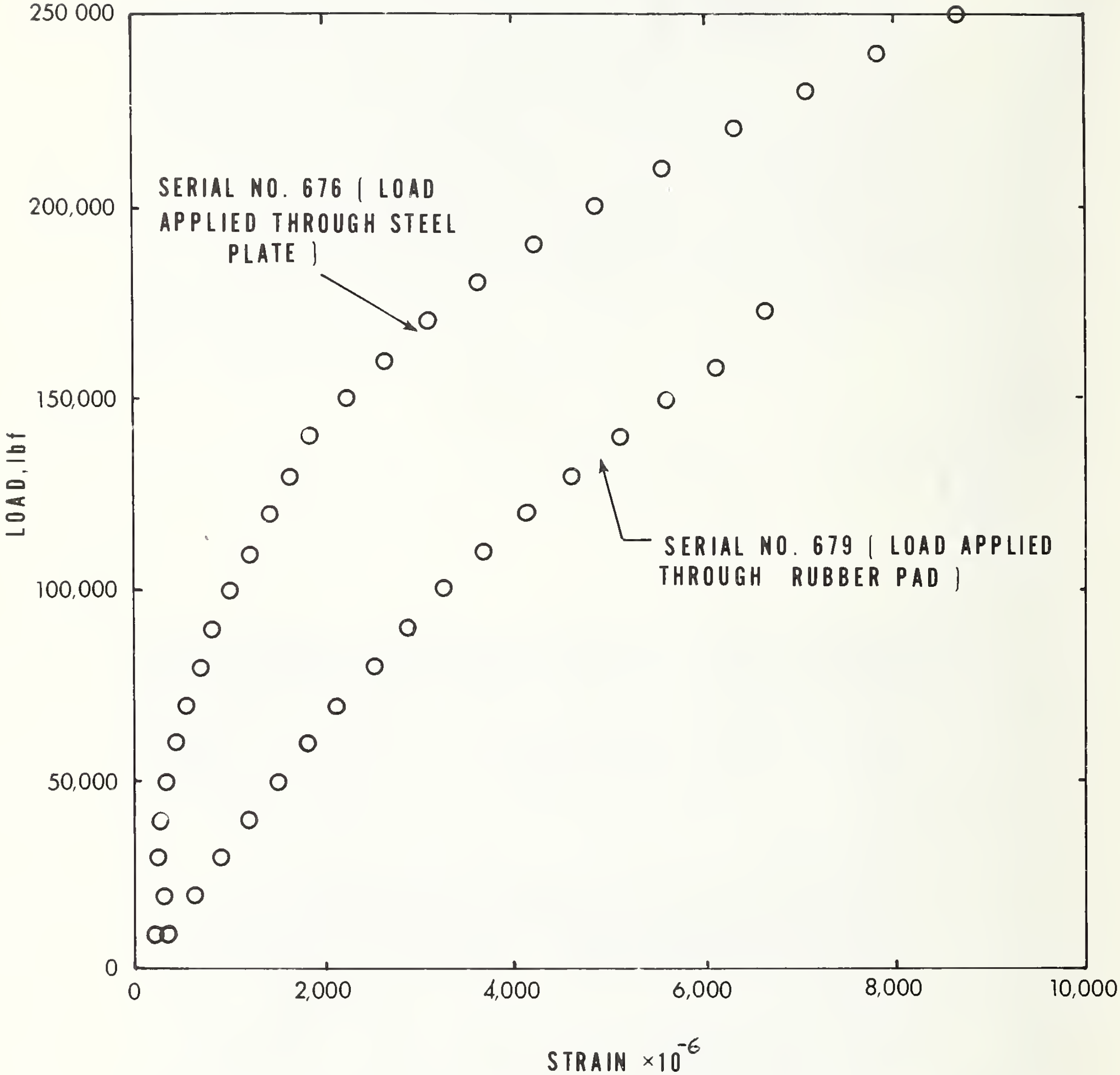

Figure 9 – LOAD VERSUS STRAIN AT GAGE LOCATION 3 ON OPTICAL COVER ASSEMBLY FOR NEW STYLE FAA-E-2491 APPROACH AND THRESHOLD LIGHT

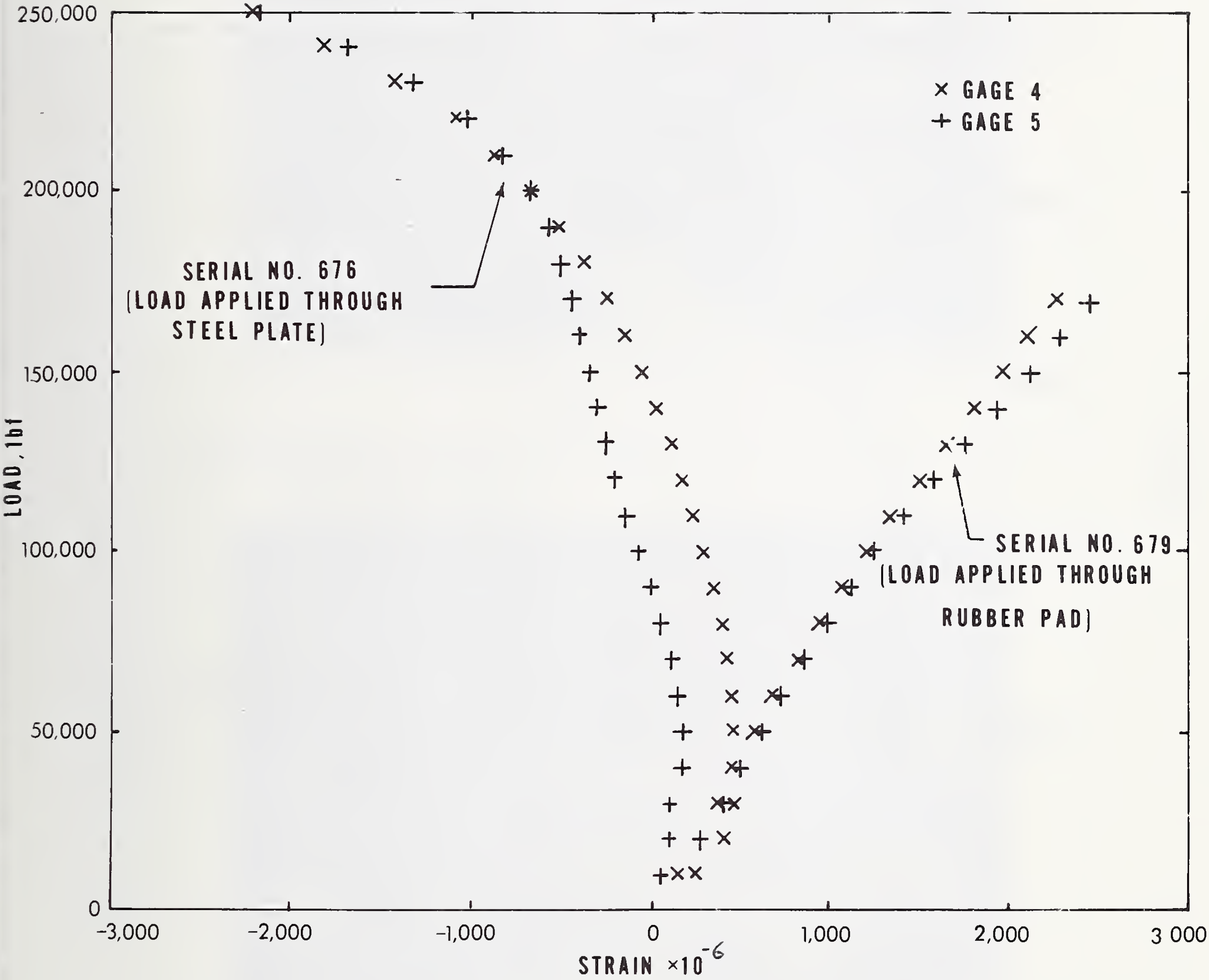

Figure 10 – LOAD VERSUS STRAIN AT GAGE LOCATION 4 AND 5 ON OPTICAL COVER ASSEMBLY FOR NEW STYLE FAA-E-2491 APPROACH AND THRESHOLD LIGHT

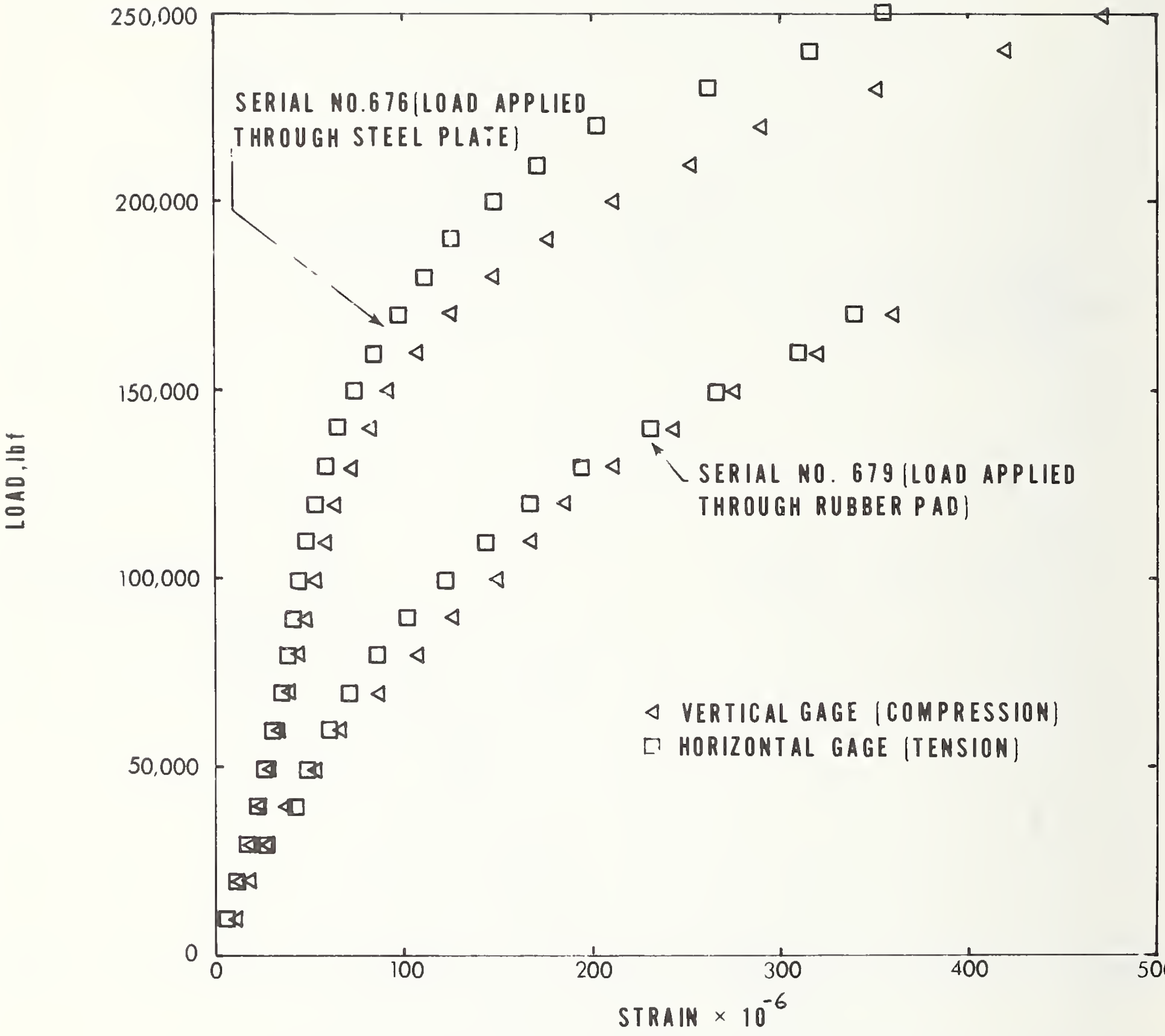

Figure 11 — LOAD VERSUS STRAIN AT CENTER OF PRISM FOR NEW STYLE FAA-E-2491 APPROACH AND THRESHOLD LIGHT

Figure 12 — Fracture of Optical Cover Assembly of Old Style FAA-E-2491 Light After Static Test Using 6-Inch Diameter Steel Plate

Table 1 - Summary of Static Load Tests of FAA-E-2491 Approach and Threshold Lights

Style	Serial Number	Loading Fixture	Maximum Load, lbf	Failure Mode
Old	267	6-Inch Diameter Steel Plate	80,000	No evidence of failure
Old	267	6-Inch Diameter Steel Plate	316,500	Casting fracture and prism rotation
New	676	Rubber Pad and Large Steel Plate	76,000	No evidence of failure
New	676	6-Inch Diameter Steel Plate	254,500	Prism fracture
New	678	6-Inch Diameter Steel Plate	262,500	Prism fracture
New	679	Rubber Pad and Large Steel Plate	174,000	Prism fracture
Old	664	Rubber Pad and Large Steel Plate	212,000	Prism fracture

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Static and impact load tests were performed on two style FAA-E-2491 airport in-pavement approach and threshold lights which were mounted in light bases encased in concrete. Static tests were conducted using either a 6-inch diameter steel plate or a rubber pad through which loads were applied to the center of the light optical cover assembly. Drop tests were conducted using a 5-lb steel ball which was directed to impact at various locations on the optical cover assembly. The old style lights were found to comply with load requirements for the current specification. The maximum load sustained by both style lights when loaded through a rubber pad was about two-thirds of the maximum load sustained when loading directly through the steel plate. A discussion is given of the photometric measurements of the light beam displacement measured during the load tests, the deflections and strains of two new style lights measured under two loading conditions and the test procedures for determining the performance of approach and threshold lights.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Airport approach and threshold lights; glass prism; impact tests; light bases; optical cover assembly; photometric measurements; static tests.

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